Performance Analysis of M-ary Optical CDMA in Presence of Chromatic Dispersion

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Abstract— **The performance of M-ary optical code division multiple access (OCDMA) is analytically investigated in presence of chromatic dispersion. The study is carried out for single mode dispersion shifted and non dispersion shifted fibers. Walsh code is used as user address. The p-i-n photodetector is used for optoelectronic conversion process. In our proposed model 16 different symbols are modulated with different intensity levels and detected by direct detection technique. The numerical results show that, the reconstruction of the transmitted symbol is strongly dependent on the received symbols magnitude which is reduced by fiber length and symbol rate. It is found that the proposed OCDMA system shows better performance when dispersion shifted fiber is used as a communication medium.**

Index Terms— **M-ary OCDMA, Chromatic dispersion, Walsh code, and p-i-n photodetector.**

I. Introduction

Optical code division multiple access (OCDMA) technology becoming attractive due to its inherent features, such as asynchronous flexibility and decentralized networking, total bandwidth utilization by all network users and potential of data security [1]-[5]. In CDMA technique, a bit is converted into several short duration chips that require more system bandwidth depending on the number of encoded chips. It is well established that M-ary modulation is bandwidth efficient in which a symbol is constructed by several bits. In previous studies [6]-[7] it was shown that the spectral efficiency of M-ary OCDMA transmission can be improved by the order of n in comparison with traditional binary OCDMA, where n is the number of bits used to form a symbol. Until now, researches on OCDMA mainly focused on direct time spread OCDMA [8], spectral encoding–decoding, pulse position modulation OCDMA, asynchronous phase-encoding OCDMA [9], frequency hopping OCDMA [10], and direct sequence OCDMA [11]-[12]. Most of previous researches on OCDMA are carried out considering the effect of fiber chromatic dispersion, which causes spreading and overlapping of chips and degrades system performance due to increased interchip interference and reduced received optical power. So far our knowledge there is no study on M-ary OCDMA in presence of fiber optic dispersion. In this paper, the performance of M-ary OCDMA is presented studied in presence of chromatic dispersion of dispersion shifted fiber (DSF) and non dispersion shifted fiber (NDSF) employing 16-ary ASK modulation. In this work, Walsh code is used as chipping sequence and p-i-n photodiode is selected as the system receiver. The effect of shot noise, thermal noise current is considered to evaluate the SNR of the proposed system. The BER performance of the proposed M-ary OCDMA is evaluated both for DSF and NDSF as a function of system parameters. We have determined the optimum value of fiber length both for DSF and NDSF for which the symbol can be recovered. Effect of spreading factor over the output symbol recovery has also been determined.

II. System Description

We consider an intensity modulation and direct detection M-ary OCDMA system. In the transmitter, a user's binary data is converted to symbol by bit to symbol converter. The decimal value corresponding to each symbol is obtained by binary to decimal converter. Then the decimal value is modulated by a bipolar signature sequence and an optical ASK modulator. The optical encoded signals of N number of users are coupled using an N: *1* coupler and transmitted through fiber optic transmission medium. The loss of optical signal in the fiber is assumed to be 0.2 dB/km and the dispersion coefficients are considered to be 3.5ps/(km.nm) and 17ps/(km.nm), for DSF and NDSF, respectively. The communication is performed at 1550nm. In the receiver, a particular user data symbol is recovered by the correlation operation using an optical correlator receiver. The decoded signal is incident on the p-i-n photodetector. The output signal magnitude is determined by a level detector and then the output symbol is recovered by decimal to binary converter.

III. Mathematical Analysis

In this proposed model it is assumed that the data signals and the chip signals have no relative delay although the signals from various users may have a certain amount of delay. This delay is not considered in this model. The product signal for k-th user can be represented by (1).

$$r_k(t-\tau_k) = \alpha_k(t-\tau_k)S_k \tag{1}$$

Here, S_k is the symbol magnitude for k-th user, $\alpha_k(t)$ is the chip sequence for k-th user, τ_k is the delay of k-th

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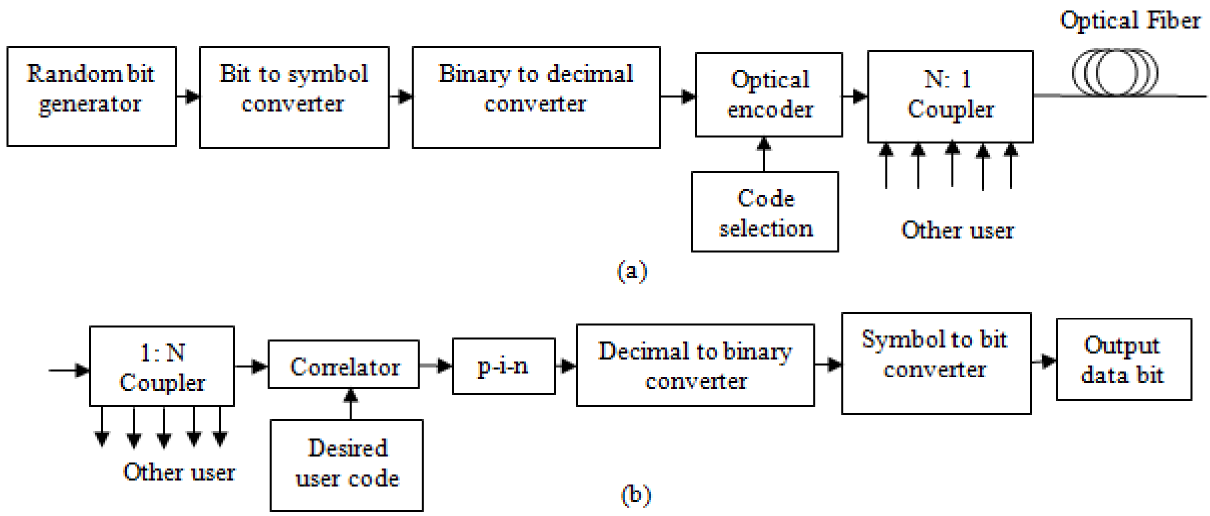

Fig. 1: Schematic block diagram of proposed M-ary OCDMA system: (a) transmitter with transmission medium, and (b) optical correlator receiver

user. $\alpha_k(t)$ is binary chip sequences with values -1 and +1. In this simulator, it is assumed that the chipping sequence is repeated for each symbol period for a particular user. The chip sequence $\alpha_k(t)$ is of the form,

$$\alpha_k(t) = \sum_{j=-\infty}^{\infty} \sum_{i=0}^{F-1} \alpha_{k,i} \prod \left(\frac{t-(i+jF)T_c}{T_c}\right) \qquad (2)$$

where, F is the spreading factor or the number of chips per bit, T_c is the chip period, FT_c is the repetition period of the chipping sequence which is equal to the symbol period T_s of a user. $\prod(t)$ represents the unit pulse function and i is an index to denote the particular chip within a Walsh chip sequence.

If the total number of users is N then the compound signal that is to be transmitted through optical fiber is given below.

$$R(t) = \sum_{k=1}^{N} r_k(t-\tau_k) \qquad (3)$$

The Fourier transform of the compound signal is given by

$$R(f) = F[R(t)] \qquad (4)$$

Now, if the transfer function of the fiber be H(f) then the signal at the end of the becomes

$$G(f) = R(f)H(f) \qquad (5)$$

After correlation operation, the signal for the k-th user can be given by

$$g_k(t) = g(t) \otimes \alpha_k(t-\tau_k) \qquad (6)$$

where the operator $\otimes$ is denotes convolution, and. $g(t) = F^{-1}[G(f)]$. After photodetection, the received signal can be given by

$$g_{out}(t) = g(t) + g_n(t) \qquad (7)$$

where $g_n(t)$ is the noise signals. In our analysis, thermal noises, shot noise of the receiver are considered. To reduce the effect of noise, the received signal is passed through a low pass filter having transfer function $H_f(f)$. Thus the signal at the filter output can be given by

$$y_{out}(t) = F^{-1}[G_{out}(f).H_f(f)] \qquad (8)$$

The output symbol magnitude of k-th user is

$$Z_o = |y_{out}(t)| \qquad (9)$$

IV. Results And Discussion

The influence of chromatic dispersion on the performance of M-ary OCDMA is analytically investigated. The simulation is carried out for a DSF and NDSF operating at 1550nm. The simulation results are calculated as a function of fiber length, symbol rate, and dispersion coefficient. Fig. 2 shows the plot of received symbol magnitude versus fiber length when symbol rate = 1Gb/s, dispersion coefficient =18ps/(km.nm), and spreading factor = 16. It is found that the transmitted symbol magnitude decreases with fiber length due to dispersion. In this simulation a symbol is constructed with 4 bits with a combination of 1101 whose decimal value is 13. So a symbol of 13 magnitude can be successfully recovered at the receiver when fiber length is about 16.5 km as seen in fig. 2. The similar result is found to be approximately 32.5km from fig. 3 when spreading factor increases from 16 to 32. This demonstrates that only increasing the spreading factor the transmission length can be increased in M-ary OCDMA system. Fig. 4 shows the plot of received symbol magnitude verses fiber length when symbol rate = 1Gb/s, spreading factor =16 and dispersion coefficient = 3.5 ps/(km.nm). In this simulation symbol value is 13. So a symbol of 13 magnitude can be successfully recovered at the receiver when fiber length is about 40 km as seen in Fig. 4 when dispersion coefficient decreases from 18 to 3.5 ps/(km.nm).

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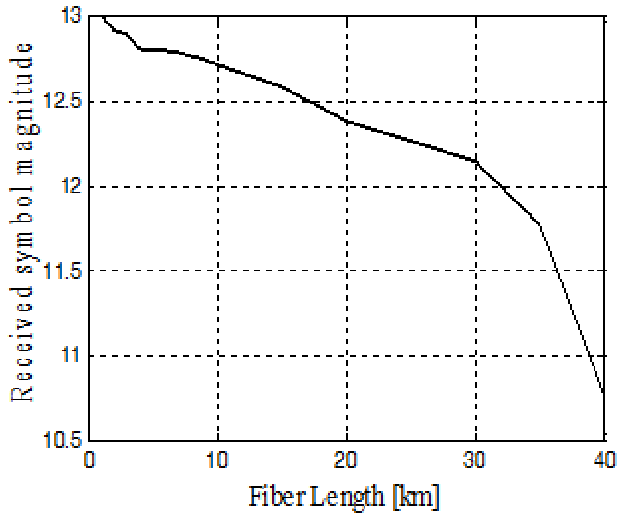

Fig. 2: Plot of received symbol magnitude versus fiber length when symbol rate = 1Gb/s, and spreading factor = 16 for NDSF

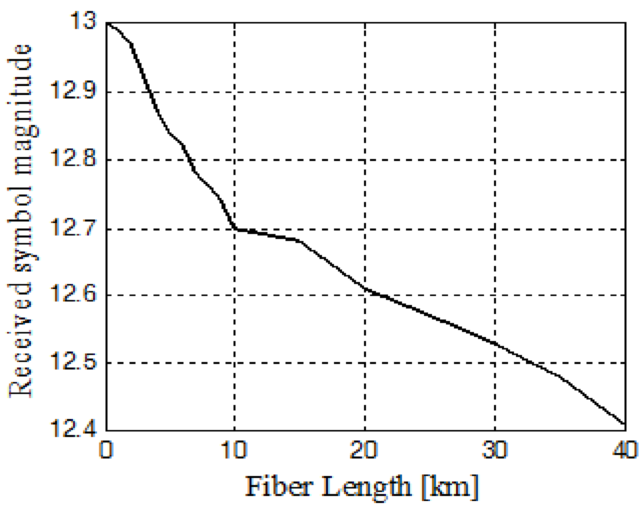

Fig. 3: Plot of received symbol magnitude versus fiber length when symbol rate = 1Gb/s, and spreading factor = 32 for NDSF

This demonstrates that decreasing the dispersion coefficient the transmission length can be increased in M-ary OCDMA. Fig. 5 show the plot of received symbol magnitude versus fiber length when symbol rate = 5Gb/s, dispersion coefficient =18ps/(km.nm), and spreading factor = 16. In this simulation a symbol is constructed with 4 bits with a combination of 1001 whose decimal value is 9. So a symbol of 9 magnitude can be successfully recovered at the receiver when fiber length is about 2km as seen in fig. 5. This demonstrates that with increasing the symbol rate the length is decrease in M-ary OCDMA. From fig. 6, it is found that the transmitted signal magnitude decreases with symbol rate due to dispersion. In this simulation a symbol is constructed with 4 bits with a combination of 1001 whose decimal value is 9. So a symbol of 9 magnitudes can be successfully recovered at the receiver for symbol rate of 4.5Gb/s when length of the fiber is 10 km as seen in fig. 6.

So from the above simulation the effect of optical fiber length, dispersion coefficient, spreading factor, and symbol rate on the proposed M-ary OCDMA system can be easily understand.

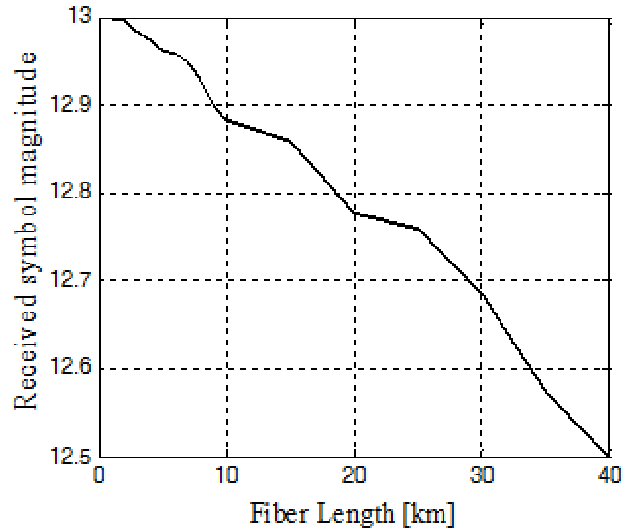

Fig. 4: Plot of received symbol magnitude versus fiber length when symbol rate = 1Gb/s, and spreading factor = 16 for DSF

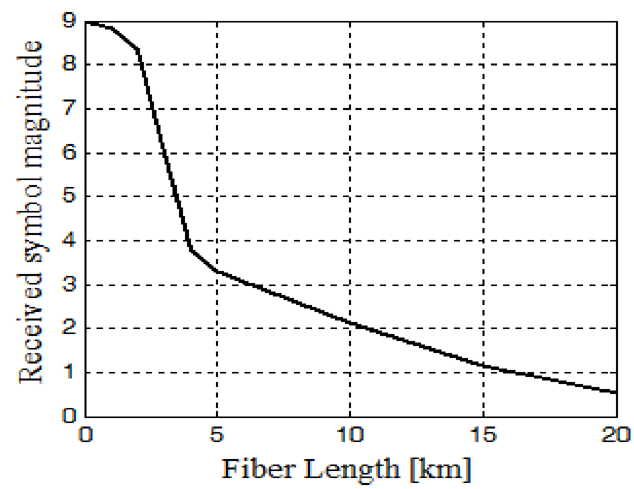

Fig. 5: Plot of received symbol magnitude versus fiber length when symbol rate = 5Gb/s, and spreading factor = 16 for NDSF

V. Conclusions

In this paper, the performance of 16-ary OCDMA system has been analyzed in presence of chromatic dispersion. It is found that increasing spreading factor; symbol can be recovered for more transmission length. But increasing the spreading factor, bandwidth requirement increases. It is also found that less bandwidth is needed in 16-ary OCDMA system compared to conventional binary OCDMA system. So, it is conclude that OCDMA system performance can be improve by M-ary with large spreading factor. In future the BER performance of M-ary OCDMA for different symbol rate, spreading factor, fiber length and number of users will be analyzed.

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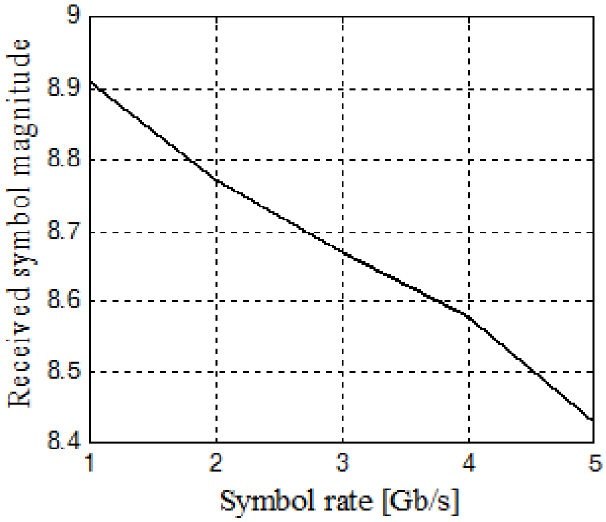

Fig. 6: Plot of received symbol magnitude versus symbol rate when fiber length = 10km, and spreading factor = 16 for NDSF

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